

In the Specification

Please insert the following paragraphs between paragraphs [0004] and [0005]:

Generally, referring to FIG. 1, an AC synchronous superconducting motor 200 includes a rotor support 202 mounted on a rotor shaft 204a and 204b. Rotor windings 206 are arranged around the support forming a rotor assembly. The assembly is mounted inside a stator cavity 208. The stator includes a plurality of stator windings 210 arranged to form cavity 208. A DC current is provided to rotor windings 206 which generates a rotor field inside cavity 208. An AC current is provided to stator windings 210 which generates a magnetic field therearound located at least partially within cavity 208. By time varying the AC current, the stator field is caused to rotate about cavity 208. The rotor and stator fields interact and, as the stator field rotates about cavity 208, the rotor follows.

Three important motor criteria for any type of motor are size, power output and efficiency. High power and small size are desirable without compromising efficiency. These three criteria do not always go hand in hand. For example, the simplest way to increase motor output is to increase stator and rotor currents. Increased currents result in stronger stator and rotor fields and therefore stronger attraction between the fields.

Unfortunately, as currents are increased, so to is the heat generated by the currents as the currents pass through the stator and rotor windings. The energy spent to generate heat constitutes a large portion of input energy losses. Higher heat means less efficient motor operation. At some point, stator and rotor current levels reach a value where generated heat reduces motor efficiency below a specified level. In these cases, generally, to increase output further, motor size must be increased.

Recent advances in superconductivity have facilitated the design of synchronous motors which generate relatively high power output for their size when compared to conventional motors. To this end, some motors have been developed which include superconducting rotor coils capable of carrying massive amounts of current through relatively few windings. Thus, where superconduction can be achieved fewer windings can accommodate increased currents and rotor girth and length can be minimized thereby reducing overall motor size.

In order to facilitate superconduction, conductors have to be extremely cold (i.e. approximately 5 degrees K for low temperature superconductors). To this end, referring again to FIG. 1, the superconducting rotor winding support 202 is located inside a vacuum jacket 209. The vacuum is absolutely necessary to provide adequate thermal insulation from heat in the ambient around the rotor. At least one shaft end 204b is typically hollow, end 204b forming a passageway 214 therethrough. Hollow end 204b is connected to a refrigeration system 216 which provides a cooling agent (e.g. liquid or gaseous helium) to the support 202 via a supply tube 207 which cools the support 202 and thereby maintains cold rotor windings 206. In addition, first and second torque tubes are typically provided which spatially isolate first and second shaft ends 204a and 204b, respectively, from support 202.

Torque tube design and features are generally governed by tube functions. Tubes 212a and 212b are usually formed of stainless steel. Stainless steel is a non-magnetic metal with relatively low thermal conductivity (for metals), which is important for thermal insulation, and is strong enough to withstand high rotor torque. The tube length is typically relatively long since longer tubes attenuate heat transfer to the rotor support.

In addition to general shape, length and material, tube functions can also be used to identify optimal tube wall thickness. As indicated above, tubes 212a and 212b must both isolate support 202 from ends 204a and 204b and must impart shaft

torque to support 202. To improve isolation, tube wall thickness is typically kept to a minimum thereby providing a mechanical "heat bottleneck" between ends 204a, 204b and support 202. However, to ensure structural integrity during torque transfer, there is a minimum wall thickness requirement. The minimum thickness is typically a safe thickness plus some additional girth to account for tube imperfections.

Unfortunately, typical tube construction and superconducting rotor configuration often lessen the advantages associated with superconducting motors. Because tubes 212a and 212b are provided between ends 204a and 204b and support 202, the tubes directly increase overall motor size. For example, where each tube 212a and 212b is eight inches long, overall motor length $L_{sub.1}$ (see FIG. 1) must be increased by sixteen inches to accommodate the tubes. Thus, tubes 212a and 212b minimize the superconducting size advantage.

In addition, while tubes 212a and 212b are mechanically constructed to minimize heat transfer from ends 204a and 204b to support 202 and stainless steel has relatively low thermal conductivity when compared to other metals, stainless steel conducts significant heat. Thus, tubes 212a and 212b conduct heat from ends 204a and 204b to support 202 and windings 206. To compensate for heating losses and maintain low temperatures in the support structure, the size and power of the refrigeration system must be increased. This power increase in turn results in a less efficient motor as increased power for refrigeration must be factored into the efficiency calculation as a loss.

One solution to reduce tube heating is to form tubes 212a and 212b out of a thermally insulating material such as a composite including bonded glass fibers and an epoxy resin (hereinafter referred to as a "glass-epoxy composite" or simply a "composite"). To this end, each tube 212a and 212b may include a composite cylinder having first and second ends to be connected to shaft ends 204a, 204b and support 202, respectively. Unfortunately, it has proven particularly difficult to satisfactorily secure such a composite cylinder to the shaft ends and support.

It has been found that to withstand high motor torque, composite fibers should be arranged about a rotation axis at an angle (e.g. 45.degree.) with respect to the axis such that the fibers extend at least partially axially along the tube. One way to secure a tube to a rotor winding support or a shaft end is to use a plurality of bolts, rivets or the like.

The bolts, rivets, etc., can be tightened onto the composite in the radial direction (i.e. through the composite cylinder wall essentially perpendicular to the rotation axis and fiber lengths). To this end, each of the shaft ends may include a coupler port and the support may include two oppositely facing coupler ports for receiving and securing adjacent cylinder ends. Each port would axially overlap and bolt to an adjacent cylinder end along a connection distance radially of the cylinder wall.

While heat transfer could be minimized in this manner, motor size would likely be increased to accommodate required tube connection distances. This is because the connection distance required to provide a sufficiently strong joint between the tube and plate ends is relatively long. For example, experiments have shown that to provide a sufficiently strong cylinder-port joint, each connection distance may be on the order of 4 inches. For this reason, because there are four joints (i.e. one at each end of each of the two tubes), the joints will often increase motor length by as much as 16 or more inches.

Another way to secure a composite cylinder to a support or shaft end would be to use an adhesive bond therebetween. Unfortunately, the bond provided by this solution is typically not strong enough to withstand motor torque and shaft stresses over extended operating periods.

A shear modulus is a constant associated with a material which indicates the amount of stress which occurs within the material when a shear deformation is

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applied across a surface thereof. Metal typically has a shear modulus which is much greater than a glass-epoxy composite shear modulus. When tubular members formed of materials having disparate shear moduli are adhesively bonded along a joint, torsional stress concentration points typically result along the length of the joint. These stress concentration points are referred to herein as singularity points. Usually singularity points will initially occur at the boundaries of the joint (i.e. at either end).

Because virtually all torque is transferred through the vicinity of singularity points and little is transferred through the rest of the joint, the bond at the joints will often fail. Once a bond fails, other singularity points along the joint length occur and the bonds thereat eventually fail until, after a period, the entire joint fails. This is unacceptable in the motor environment and therefore adhesive joints have not as of yet been used in the electrical superconducting machinery torque tube art.